LDSP: Shopping with Cryptocurrency Privately and Quickly under Leadership

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Shopping with Cryptocurrency?

😊 Slow
- Bitcoins takes 10 mins to include a payment transaction
- (~60 mins to confirm)

😢 Low Privacy
- All transactions are exposed on the blockchain
Traditional Layer-2 Networks

😊 Low-latency Payment
- Payer & payee confirm their payment “locally” (off-chain)
  - jointly-sign a balance sheet of their (updating) asset & sync “on-chain” later

😢 High collateral: money locked (mostly) for a single payee

😢 Constantly-Online Requirement
- Payers & payees need to monitor the on-chain transactions
  - worry that the other party might upload an “outdated” balance sheet

😢 (Still) Low Privacy
- The final balance sheet is exposed on the blockchain
  - total transaction amount & who paid to whom are leaked
Snappy: Layer-2 Solution for Retail

- *Unidirectional* system tailored for *retail* payments [NDSS 20]
  - Users take the role of either *customer/payer* or *merchant/payee*

😊 **Low-latency** Payment Solution (~ layer-2)

😭 **Offline** Customer (no need to monitor on-chain)
  - Merchant has *disincentive* in uploading *outdated* sheet
    - Penalty from their collaterals

😆 **Low Collaterals**
  - Customer collateral is “*shared*” among all merchants in Snappy
Shortcomings of Snappy

😊 No Privacy (Merchants share all Payer Spending Histories)

- State = all payer’s spending histories
- Merchants also serve as statekeepers
- Confirmation needs 51% of merchants to vouch
  - Each checks the balance of the payer
  - pays back from their collateral if vouched wrongly
    - e.g., a double-spending transaction
LDSP: Layer-2 Anonymous Payment

😊 Low Latency
- Speedy confirmation of off-chain payment within seconds

😊 Dynamic and Distributed Setup
- Merchants (payees) can join and leave dynamically
- Customers (payers) can pay multiple merchants

😊 Scalable On-chain Processes
- Our design naturally supports batching to reduce on-chain costs

😊 Privacy
- Customers (payers) can hide their identities
- They can “hide in the crowd” to obfuscate the payment amount
Customers, who want to pay merchants (off-chain)

A consortium, formed by a group of merchants

A leader, leading the consortium

An arbiter (smart contract), for resolving disputes, etc.
Workflow (& Core Functions)

1. Customers *withdraw* LDSP coins by funding them on-chain
2. Customers *spend* (off-chain) LDSP coins to a merchant
3. Customers *refund* unspent LDSP coins
4. Merchants *bookkeep* and *deposit* the received LDSP coins to receive the on-chain coins (funded by customers)
Dilemma: Who issue LDSP coins?

- **All** merchants (or statekeepers) are needed to issue coins
  - Not scalable!
- **Only 1** merchant (or statekeeper) is needed to issue coins
  - Keep issuing coins to a “customer” to be spent at victim merchant
  - Becomes a money-printing factory!
- **A large subset** of them needed to issue coins
  - The worst of both worlds?
  - Need many to help, but they can still collude
  - Or is it?
High-Level Operations of LDSP

- We introduce leaders, each leads a group of merchants

- Merchants in a group jointly issue coins, forming a “virtual bank”

- A coin can either be spent with the issuing merchant
- or at another merchant, which we call cross-group payments
Leader’s Duties and Motivation

- settles w/ other leaders for cross-group payments
- confirms payment (in its group) to avoid double-spending
- motivations: getting service fees, establishing partnerships
Highlights of LDSP

- Small group size, which mitigates the scalability problem
- State = which merchant gets back how many LDSP coins
  - Formed by “consensus” between the leaders and the merchants
- Merchants can belong to different “virtual banks”
  - i.e., the groups forming the banks are overlapping
- Merchants, who are payees, have no incentive to forge
Design Intuition (Merchant Perspective)

- Self-evolving ecosystem
- We leverage the “business relationship” among merchants to help their beloved customers.
- Somewhat like how inter-bank transactions are cleared
  - “I know this virtual bank well. I’ll just accept its coins.”
  - “I’m not familiar with this bank. Let me talk to them first before accepting too many coins issued by them.”
Design Intuition (Customer Perspective)

- Somewhat similar to customer-loyalty programs
- Think of the coins are the “points”/“mileages”

- “I frequent these shops. Let me get more coins from them.”
- “I may occasionally buy this each month. I’ll get less here.”

- LDSP coins are partially blind signatures from a group
- “80/20 rule”: trade a bit of privacy for better efficiency
A bit more details
Withdrawal, Payment, Refund, …
Customer’s Withdrawal

- The customer funds LDSP coins via the arbiter
- The customer uploads a blinded $h(sn)$ w/ an on-chain coin
  - $h$: crypto hash function, $sn$: (random) serial number
- The merchants \textit{jointly} sign, \textit{blindfolded}, on the $h(sn)$ as $S_{sn}$
- The customer gets the signature $S_{sn}$ as an LDSP coin
Payer Privacy

- Basically, we adopt a multi-blind signature approach.

- Hide the link btw. on-chain coins & LDSP (off-chain) coins.

- The customers thus hide among those spending coins from the same virtual bank.
Customer’s off-chain Payment

- Customer reveals the signed $h(sn)$ to the merchant & leader
- The leader confirms it with its signature $\sigma_{sn}$
- The customer reveals $sn$ to the merchant

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Customer’s Refund

- The customer uploads the opening for $h(sn)$ to the arbiter.
- If $sn$ has been spent, the merchant can reveal $sn$ to debunk.
- If no dispute, the customer gets back the on-chain coin.
The leader releases all payment records in batch
- which is uploaded to the arbiter after the merchants jointly signing on it
- The leader will be blamed if any double-spent coin is spotted
- The merchants can deposit all bookkept coins altogether later

**Merchants’ Bookkeeping (& Why no Double-Spending)**

1. $R = \{sn_1, sn_2, \ldots, sn_n\}$
2. $\sigma_{R,1}$
3. $R = \{sn_1, sn_2, \ldots, sn_n\}$
4. $\sigma_{R,2}$
5. $R = \{sn_1, sn_2, \ldots, sn_n\}$
6. $\sigma_{R,3}$
7. $\sigma_R = \text{Agg}(\{\sigma_{R,i}\}_{i \in [1:3]})$
LDSP’s Safety (No one loses money)

- Safety of the Customers:
  - They can always refund an unspent coin

- Safety of the Merchants:
  - For double-spending, they can blame the leader for compensation
  - No merchant can mint coin w/o the signature of all other merchants
Low-Latency Payment & Low On-Chain Cost

- Off-chain payment with < 512 coins is done in < 0.5s
  - Urban Network: 100 Mbps Bandwidth, ~20ms Latency

- Low on-chain cost

<table>
<thead>
<tr>
<th>Operation</th>
<th>Gas (on Ethereum)</th>
<th>USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>21000/tx</td>
<td>3.72/tx</td>
</tr>
<tr>
<td>(Batched) Withdrawal</td>
<td>38.36/coin</td>
<td>0.0068/coin</td>
</tr>
<tr>
<td>(Batched) Refund</td>
<td>25.76/coin</td>
<td>0.0046/coin</td>
</tr>
</tbody>
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based on the average gas price and exchange rate on 1 May, 2021
Summary

- **LDSP**: Shopping with Cryptocurrency *Privately* and *Quickly* under “Consortium Leadership”
  - a Low Latency, Dynamic & Distributed System
  - w/ Scalable On-chain Process, & Payer Privacy

- What’s more in the paper:
  - The use of round and epoch
  - Keeping a low on-chain cost via batching
  - Analysis on LDSP’s safety & liveness
  - How LDSP achieves low collaterals, avoids single-point-of-failure, etc.

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